Design of a High Gain & Ultra Wideband Microstrip Array Antenna for Avalanche Radar

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Abstract—**This paper presents the design and construction of a microstrip array antenna operating at 5.3 GHz, to be used as an avalanche sensor in avalanche measurement. The advantage of the antenna is it can achieve a high gain of 15.6 dB with bandwidth of 90%. This was achieved by separating the feed network from the main patches; and increasing the antenna height by installing the feed layer at the back of the patch layer, sharing the same ground plane. In order to ensure the power is transferred smoothly from the main input port, the feed is design in novel spider like tapered feed network while ensuring the overall antenna function is not compromised.**

Index Terms--- microstrip array antenna; avalanche radar; high gain antenna; ultra wideband antenna

Introduction

Avalanches have been proved to post a threat to the humankind. A better understanding of the avalanche flow is deem important to calibrate computational models of avalanches which are an essential tool in formulating risk zones for settlements and flows. Current non-invasive systems deployed for the purpose of gathering avalanche flow data include buried FMCW radar, pulsed Doppler radar and video recorders (1). The radar system is then deployed at avalanche test site where artificially triggered avalanches can be measured. Several of this test sites exist in Europe (2).

Currently, almost all of the sensors use parabolic dishes due to its' high gain capability over a long-range distance. This only has the capability to gather coarse (50m) range and Doppler information. A new C-band FMCW radar system has been developed to gather high-range resolution, two-dimensional, animated radar images of entire avalanche events. This could be achieved by placing the antennas in a phased array manner; which is not suitable if heavy parabolic dish is used. Apart from that, due to the space constraints in the bunker, the feasibility of installing the radar and to be able to integrate with the radar transmitter and receiver; a microstrip antenna design is proposed.

Microstrip antenna are widely used in weather radar, remote sensing and radio astronomy due to its' capabality of miniaturization and integration with other parts of the radar system. Microstrip antennas are particularly suitable for integration with other active devices to create such applications due to their low profile, reduced weight, small size and low cost (3). However, microstrip antennas also come with limited functionalities such as low gain, narrow bandwidth and low efficiency. For the avalanche radar project, a high gain antenna is of particular interest since the terrain and snow particles are exposed in a large and wide area in the avalanche test site. A typical way to increase the gain is by arranging the patches in an array format. A couple of other studies has revealed that gain enhancements of microstrip antennas could be achieved by adding multiple superstrates over the substrates layer (4, 5, 6) and some even applied it to stacked parasitic patches (7) in order to achieve a high gain microstrip antenna.

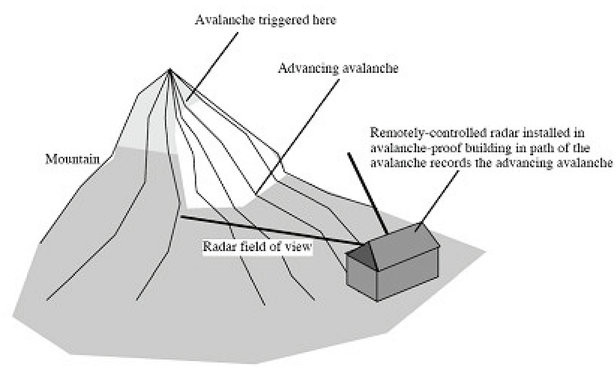

Figure 1. The bunker placement in front of the avalanche track

The efficiency of a microstrip array antenna also depends on the feed network. Normally, corporate-fed network is used to achieve a broadside beam with uniform distributions. The main drawback for this feeding structure is it takes a considerably amount of space as the number of patches increases. This would also increase the feedline, which would also increase the conductor and dielectric loss and also increase the spurious radiation by the feedline. Thus, it is important to separate the feed network from the overall performance of the antenna to ensure the antenna works at its' optimum efficiency. This has been suggested by (8), where an improvement to the antenna performance could be seen as the feed network is separated from the main radiating parts.

In order to obtain a wide detection range especially in the elevated angle; the main slope of the avalanche track, the receiving array is arranged to give a relatively wider beamwidth on the elevation plane and a narrower beamwidth in the azimuthal plane. The eight receiving array will also be placed in four separate windows of the bunker to cover the

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azimuthal plane and in a random arrangement to ensure grating lobes does not affect the array performance. The placement of the bunker could be visualized in Figure 1.

In this paper, a design of two layers microstrip array antenna, with a separated feed network on the second layer is proposed to achieve a high gain antenna as well as keeping the feed radiation out from the antenna performance equation. A novel spider-type feed network is proposed to achieve a uniform distribution as well as keeping the sidelobe level at a minimum and maintaining the gain at the desired level.

System Requirements & Antenna Parameters

The avalanche radar is designed to operate at 5.3 GHz. This frequency is used because it can penetrate the suspended cloud region and illuminate the underlying dense region of the avalanche flow at the test site that is composed by larger particles.

The scan range for the avalanche track, which can be used to determine the needed beamwidth of the antenna, is represented in Figure 2. From the system requirements, the eight-received array that is randomly sampled will be placed linearly in four of the bunker windows. The random spacing is needed to overcome the effects of grating lobes, which will normally occur in uniformly spaced antennas. The antenna will be inclined at an angle of 10°, with each array having the azimuthal scan range of 100m and elevation scan range of 500m to cover most of the avalanche tracks. The specifications of gain and 3 dB beamwidth will be determined to satisfy these conditions.

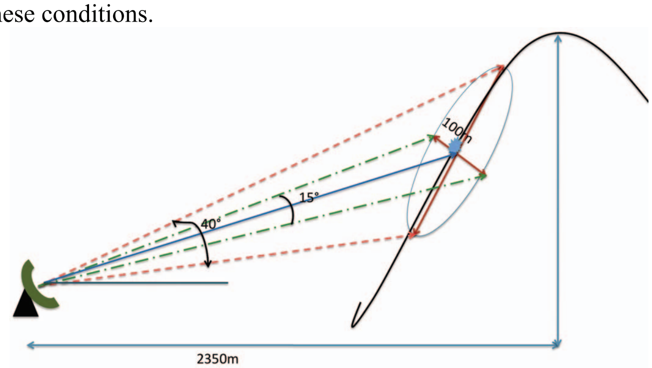


Figure 2- Beamwidth calculation from the a avalanche site characteristics

First, the expected gain of the receiving antenna is mainly determined with the other sensors that have been installed for the avalanche trials. All the other sensors are using parabolic dishes due to its' high gain capabilities. Due to that, the receiving antenna design should also have high gain of 18-20 dB.

Second, the azimuthal beamwidth of the antenna could be deduced from figure 2, which is given as:

$$HPBW_{azi} = 2\tan^{-1}\left(\frac{500m_{scan\_range}}{2350m_{radar\_range}}\cos 80^{o}\right) \quad (1)$$

The elevation beamwidth of the antenna is determined by the radar range equation in (2) and the Minimum Detectable Signal of the FMCW Radar. The calculated MDS from the link budget in (1) is -110 dBm.

$$P_r(\theta,\phi) = \frac{\sigma G_t(\theta,\phi) G_r(\theta,\phi)}{4\pi}\left(\frac{\lambda}{4\pi R^2}\right)^2 P_t \qquad (2)$$

The RCS (radar cross section) of the target, σ is -15 dB from (9) and the transmit power is 15 Watts. G_t and G_r is the gain pattern taking into account the beamwidth. These yield an azimuthal beamwidth of 15° and elevation beamwidth of 40°.

Antenna Design

The main concern while designing this antenna is to achieve a comparable high gain antenna while maintaining the low weight, small size and a low profile antenna due to the over crowding situation already occurring in the bunker at the test site. We have determine three ways to achieve this while ensuring the gain and the size of the antenna is not compromised:

A. Multilayer Antenna Design

The proposed design of using two layers in the antenna design is to increase the height of the antenna and to separate the feed network from the radiated patches itself. The configuration of the design could be seen in Figure 3, where the topside consists of the patches and the bottom side is the feed network. Both layers are sharing the ground plane and the patches are fed from the feed using shorting vias. These configurations have the advantage of increasing the antenna gain and also keeping out the losses (ohmic, conductor, line and dielectric) generated by the feed network in the overall antenna performance. Additionally, buy installing the feed at the back of the patches, we are also conserving a big amount of space that is usually needed for the coporate feed network.

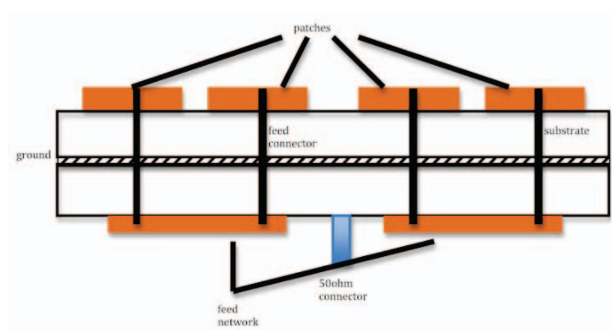


Figure 3 – Side view profile of the antenna design

B. 4 X 2 Array Configuration

In (10), it has been proved that in order to reduce the amount of clutter from the radar received signal, a narrow beamwidth system is preferable for the application. One of the ways to achieve a narrow beamwidth antenna is by arranging the patches in an array format. We can see from Table 1, as the number of patches increases, the beamwidth tends to be narrower. This result is obtained by using the antenna simulation software from CST.

TABLE I. EFFECTS ON NUMBER OF PATCHES ON ANTENNA PARAMETER

Array Configuration	Gain (dB)	Elevation Angle (°)	Azimuthal Angle (°)
2 X 2	7.97	78.7	72.9
3 X 3	17.93	23.2	22.8
4 X 1	14.19	73.3	17.0
4 X 2	16.91	35.7	17.0
4 X 3	19.35	22.2	17.0
4 X 4	20.48	17.4	17.0

Another important effects that could be seen from table 1 on choosing the arrays of patches as opposed to a single patch is because as the number of patches increases, the gain also increases. From the same table, we could also deduce that the array configuration of 4 X 2 patches is the most suitable arrangement for our receiving antenna. The fabricated antenna could be seen in figure 4. In order to prevent grating lobes from appearing in the radiation pattern, the distance of the antenna is kept at 0.65λ.

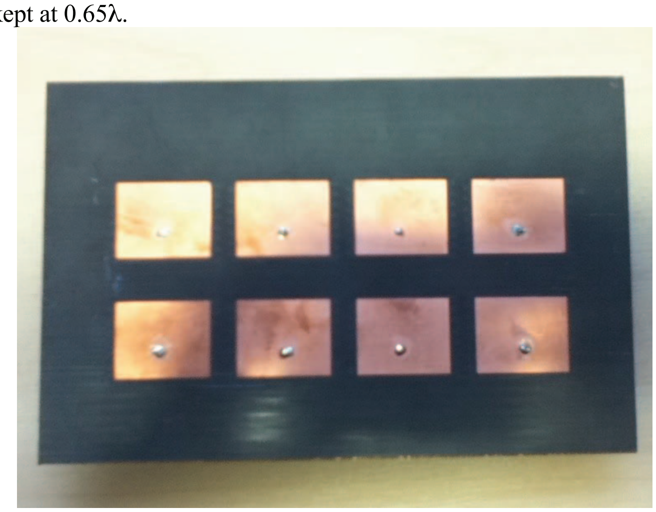


Figure 3 – The Topview of the Antenna Patches

C. *Novel Feed Network*

In this 4 X 2 array design, we are going to use a corporate feed network to supply a uniformly distributed power to all eight of the patches. We are also using the tapered line and no right angles for the feed bends in order to ensure a smoother transition of impedance. A quarter-wave transformer is also used wherever an impedance matching is needed. The novel spider-like feed network constructed is as displayed in Figure 4.

The feed network is constructed from 100Ω impedance of the patches to achieve a shunt of 50Ω in between the two patches. Then, the 50Ω feed line is constructed and is bend in a semi-hexagonal manner until the main feed line. Just before the main feed, the 50Ω feedline is tapered into the main feed that connects it with the SMA input power connector. The feed is checked with CST before being fabricated for real measurement. The overall antenna performance is also checked with CST before sending for fabrication.

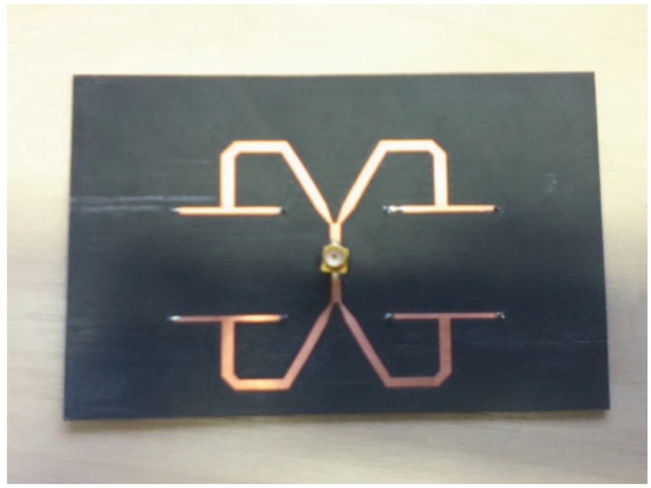


Figure 4 – The Bottom view of the Spider-like Feed Network.

RESULTS & MEASUREMENTS

The overall antenna dimension is 14 X 9 cm. The return loss of the antenna could be observed in Figure 5. The figure shows a span of frequency from 4 GHz to 8 GHz and at the desired frequency of 5.3 GHz, a return loss value of -22 dB is achieved. From the same plot we could also see that the bandwidth of the antenna is quite broad with the S11<-10dB occurring at almost 90% of the span.

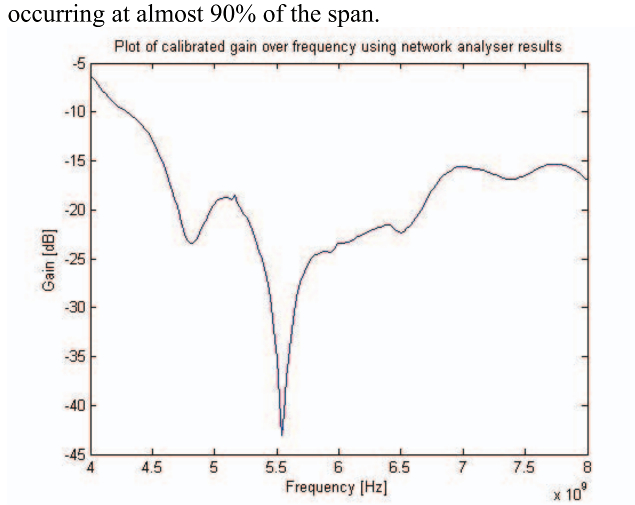
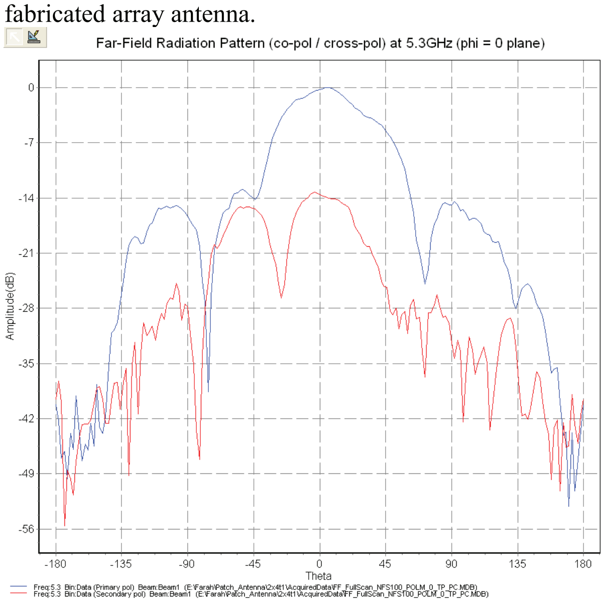
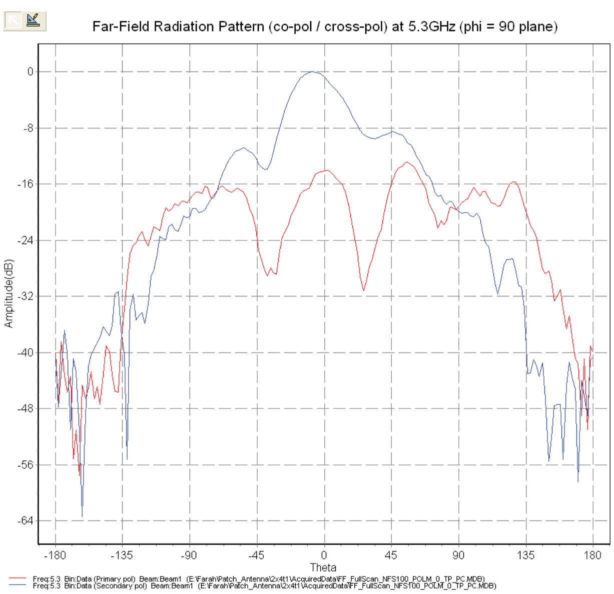


Figure 5 – Antenna Return Loss from Network Analyzer.

The fabricated antenna is also tested in the Spherical Near Field Chamber (SNFM) to determine the radiation pattern and the gain of the antenna. The cross-polarization and copolarization of both azimuthal and elevation angle is displayed in Figure 6. From the plot we could see that the achieved beamwidth from the fabricated antenna is 25° for the azimuthal plane and 45° for the elevation plane. From the SNFM software, the gain of 15.6 dB is achieved from the fabricated array antenna.



(i) Azimuthal Plane



(ii) Elevation Plane

Figure 6 – The beamwidth of the antenna from SNFM plots

I. Conclusions

In this paper, a high gain microstrip array antenna for avalanche radar was designed, fabricated and tested. The high gain traits are achieved by the combinations of three design criterias of the antenna: the multilayer substrates; an array of 4 X 2 patches; and a novel spider-like feeding network. The targeted design gain is 18 dB with beamwidth of 15° X 40° for the azimuthal and elevation plane.

The measured pattern of the fabricated antenna achieved beamwidth coverage of 25° X 45° with a gain of 15.6 dB. Although the achieved beamwidth and gain differ slightly from the calculated target, it is still acceptable for the use of avalanche radar. In Future, in order to improve the gain and make the beamwidth narrower, more patches could be added in the design. This result could also be improved with a careful approach in fabricating the antenna as it was done manually in this paper.

The advantage of achieving ultra wideband is a bonus and would be useful for other projects. Overall, the antenna is suitable to be used in a high gain application requiring an ultra wideband bandwidth as has been demonstrated in this paper.

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